Chapter 6: Resource and Energy Conservation

CHAPTER CONTENTS

CHAPTER OVERVIEW

This chapter discusses resource and energy use in flexographic printing and identifies opportunities for conservation. By minimizing resource and energy use, companies can improve the environment as well as their bottom line. Data presented in this chapter are based on information collected during the on-site performance demonstration runs and information from equipment vendors. Ink and energy consumption data presented in this chapter are used in the cost analysis (Chapter 5) to calculate ink and energy costs. Ink consumption data are also used to estimate environmental releases for the risk characterization (Chapter 3).

INK AND PRESS-SIDE SOLVENT AND ADDITIVE CONSUMPTION: Section 6.1 presents the comparative ink and press-side solvent and additive consumption rates for solvent-based, water-based, and UV-cured ink systems. This analysis is based on the weights of inks, solvents, and additives, and on the substrate usage recorded by an on-site observer from Western Michigan University (WMU) at each demonstration site.

ENERGY CONSUMPTION: Section 6.2 discusses the energy requirements of the drying systems, corona treaters, and pollution control equipment (catalytic oxidizers) typically used with the different ink systems. Electrical power and/or gas consumption data were collected by WMU and supplemented by energy estimates from equipment vendors. Due to the variability among equipment and operating procedures at the different test sites, equipment vendor estimates, rather than site-specific data, are used in the cost analysis to calculate energy costs.

ENVIRONMENTAL IMPACTS OF ENERGY REQUIREMENTS: Section 6.3 presents the environmental impacts of electricity generation and natural gas combustion, using software that quantifies emissions. The results are calculated for each ink system based on the rate of energy consumption at the methodology press speed (500 feet per minute) and the average press speeds observed at the performance demonstrations.

CLEAN-UP AND WASTE DISPOSAL PROCEDURES: Section 6.4 discusses the clean-up procedures used at the performance demonstration sites, as well as some of the broader life-cycle issues associated with energy and natural resource use.

HIGHLIGHTS OF RESULTS

- **UV-cured inks had the lowest ink consumption rates.** In addition, UV inks required almost no press-side additions. Solvent-based inks had the highest consumption rates for ink and materials added at press-side.
- **Water-based inks consumed the least amount of energy** (assuming pollution control equipment is not needed). At a press speed of 500 feet per minute, UV-cured inks were the next lowest consumer, but at the press speeds observed during the performance demonstration, solvent-based inks were the second-lowest energy consumer per unit of image.
- For solvent- and water-based inks, **air recirculation in dryer units can significantly reduce energy requirements** by increasing the temperature of the incoming air.
- **The environmental impacts due to energy production were lowest for water-based inks**. This ink system consumed the least amount of energy, and much of the energy it did use was derived from natural gas. Based on a national average of energy emissions by source, the CTSA found that natural gas released less emissions per unit of energy than electricity. Depending on the geographical location of a flexographic printing facility (and thus the specific electricity source), emissions could be very different.
- Most solvent-based and some water-based ink wastes are classified as hazardous waste. Non-hazardous waste (e.g., waste substrate and some cleaning solutions) can be recycled or reused.

CAVEATS

- Ink consumption was calculated during the performance demonstrations by recording the amount of ink added to the press and subtracting the amount removed during cleanup. Several site-specific factors could have affected the calculated ink consumption figures: type of cleaning equipment, anilox roll size, and the level of surface tension of the substrate.
- The energy consumption section only considers equipment that would differ among the ink systems. Therefore, drying/curing equipment is included, but substrate winding equipment and ink pumps are not.
- Except for corona treaters, information was not available about the difference in energy requirements when equipment is run at different press speeds. UV lamps also will have different energy demands at different energy speeds, but it is assumed in this analysis that their energy consumption is constant. Therefore, the energy consumption of UV lamps may be overestimated at lower press speeds.
- The clean-up and waste disposal procedures section presents the methods observed at the performance demonstration sites. These procedures were developed independently by the individual sites, and do not represent recommended practices by EPA.

6.1 INK AND PRESS-SIDE SOLVENT AND ADDITIVE CONSUMPTION

By reducing resource consumption, businesses can increase process efficiency, decrease operating costs, and decrease demand for natural resources. Ink is one of the main resources consumed by the flexographic printing process. The amount of ink required to print an image not only affects printing costs, but also influences the potential risk to workers and the environment from exposure to ink constituents. This section of the CTSA presents average consumption of inks and press-side additions from the performance demonstrations. The data are in units of pounds of ink consumed per 6,000 images and per 6,000 ft^2 of image, as printers commonly use these terms in estimating and comparing costs.

Methodology

The amounts of ink, press-side materials, and substrate consumed during the performance demonstrations are shown in Appendix 6-A.

The on-site observer weighed the pre-mixed ink components (extender, water, solvent, etc.) that were put in the ink sump at the beginning of makeready and whenever ink components were added to the sump. During clean-up, the observer weighed the ink remaining in the sump, the ink scraped or wiped out of the press, the cleaning solution (water, detergent, or solvent) added to the press, and the ink and cleaning solution removed from the press. The total ink consumed during makeready and the demonstration run for each color was calculated from the following equation.

$$I_{total} = I_{pre} + \sum I_{add\text{-}mk} + \sum I_{add\text{-}pr} - I_r - I_s + C_{in} - C_{out}$$

where

I_{total} = total amount of ink plus press-side solvents and additives consumed (printed or evaporated) during makeready and the demonstration run
I_{pre} = amount of pre-mixed ink put in the ink sump at the beginning of makeready
$\sum I_{add\text{-}mk}$ = the sum of additional ink components put in the ink sump during makeready
$\sum I_{add\text{-}pr}$ = the sum of the ink components added to the system during the press run
I_r = amount of ink remaining in the sump at the end of the run
I_s = amount of ink scraped or wiped out of the press at the end of the run
C_{in} = amount of cleaning solution added to the press during clean-up
C_{out} = amount of cleaning solution and ink mixture removed from the press during clean-up

Ink Consumption
Ink consumption was calculated for each demonstration site using the following information:

- total amount of ink consumed during makeready and the press run (I_{total})
- amount of substrate printed (S)
- total area of the image (16 by 20 inches with a 16-inch repeat)

Substrate consumption was recorded from the press meter at the beginning of makeready, at the end of makeready, and at the end of the press run for each substrate. The consumption numbers are listed in Appendix 6-A.

Sample calculations for white, water-based ink at Site 1 follow, to help readers understand the methodology and to allow reproducibility of results. The complete data are provided in Appendix 6-A.

Total white ink consumed (I_{total}) = 56.4 pounds (lbs)
Total substrate consumed including makeready (S) = 62,892 linear feet (ft)
Total area of image = 2.22 square feet (ft^2)
Repeat length of image = 1.33 ft

Number of images (N) = S / 1.33 feet per image
= 62,892 feet / 1.33 feet per image
= 47,200 images

Ink per 6,000 images = $(I_{total}/N) \times 6{,}000$ images
= (56.4 lbs/47,200 images) × 6,000 images
= 7.17 lbs per 6,000 images

Ink per 6,000 ft^2 of image = $(I_{total}/N) \times 6{,}000\ ft^2$ of image / Area of image
= (56.4 lbs/47,200 images) × 6,000 ft^2 / 2.22 ft^2 per image
= 3.23 lbs per 6,000 ft^2 of image

White ink was not printed on the PE/EVA substrate. Thus, PE/EVA substrate is excluded from ink consumption calculations for white ink.

Table 6.1 presents the percent area of coverage for each ink. White dominates the ink coverage of the image (60.8%), blue and green (line colors) account for 24.1% coverage, and cyan and magenta (process colors) account for 5.2% coverage.

Table 6.1 Image Area by Color

Color	Area (in^2)	Area (ft^2)	Percent coverage (%)[a]
Blue	43.5	0.30	13.6
Green	33.5	0.23	10.5
White	194.7	1.35	60.8
Cyan	8.2	0.06	2.6
Magenta	8.2	0.06	2.6

[a]The total percent coverage does not equal 100% because of overlapping colors and unprinted area.

Facilities running more than one substrate did not clean the press between substrates. Thus, only total weights, not the weight of ink applied to each substrate, are available. For the purposes of this analysis, it is assumed that the weight of ink consumed per unit area is not a function of the film type.

Press-side Solvent and Additive Consumption

During the course of a print run, printers may add solvent or water to correct the viscosity of the ink, or other components, such as extenders or cross-linkers, to improve the performance of the ink. Solvent and additive weights were calculated assuming the weight of each component consumed is directly proportional to the component weight added to the system.

The solvent and additive consumption rates were then calculated in a manner similar to the ink consumption rates.

The method for calculating ink weights assumes equal volatilization rates for each component. It does not account for solvent emissions from the ink sump or ink pan. Because solvents are expected to volatilize at a more rapid rate than other components, this method slightly underestimates solvent consumption rates and slightly overestimates rates for the other components. Sample calculations for solvent and additive weights using solvent-based, blue ink data from Site 5 follow, with numbers taken from Table 6-A.12 in Appendix 6-A:

Weight of blue ink added to system (I_{added}) = 20.90 lbs
Weight of solvent added to the blue ink (S_{added}) = 4.81 lbs
Total ink used (I_T) = 18.16 lbs

Total components added (T) $= I_{added} + S_{added}$
$= 20.90$ lbs + 4.81 lbs
$= 25.71$ lbs

Ratio of I_{added} to T (R_I) $= 20.90$ lbs / 25.71 lbs
$= 0.81$
Ratio of S_{added} to T (R_S) $= 4.81$ lbs / 25.71 lbs
$= 0.19$

Weight of ink consumed $= I_T \times R_I$
$= 18.16$ lbs $\times$ 0.81
$= 14.8$ lbs

Weight of solvent consumed $= I_T \times R_S$
$= 18.16$ lbs $\times$ 0.19
$= 3.4$ lbs

Limitations and Uncertainties

The limitations of and uncertainties in the data are related to the limited number of demonstration sites, variability among the equipment and operating procedures at the test sites, and uncertainties in the measured ink component weights. Each of these are discussed below.

Limitations Due to the Number of Demonstration Sites
Ink consumption data were collected during twelve performance demonstrations at ten flexographic printing facilities across the United States and one press manufacturer's pilot line in Germany. As such, the data represent a "snapshot" of how the inks performed at the time of the performance demonstrations (November 1996 — March 1997) under actual operating conditions at a limited number of facilities. Because no two printing plants are identical, the sample may not be representative of all flexographic printing plants (although there is no specific reason to believe they are not representative).

Variability among Equipment and Operating Procedures
Several operating parameters were specified in the performance demonstration methodology (see Appendix 6-B) in an attempt to ensure consistent conditions across demonstration sites.

These included target specifications for anilox rolls (screen count and anilox volume) which directly affect the amount of ink applied to print an image.

The specified target ranges for the anilox rolls were not always met. Because of the production needs of the volunteer facilities, changing anilox rolls or acquiring new anilox rolls to meet the specified targets was impractical. Table 6.2 lists the target anilox specifications and the average configurations by ink type for the anilox rolls actually used at the demonstration sites. The Site Profiles section of the Performance chapter (Chapter 4) lists the particular anilox configurations used at each of the test sites. Facilities using anilox volumes and screen counts greater than the specifications would be expected to consume more ink to print the test image. Similarly, facilities using anilox volumes and screen counts less than the specifications would be expected to consume less ink to print the test image. Also, these specifications do not address the fact that the anilox roll volume would differ depending on the color printed; for example, the volumes for light colors would be larger than those for dark colors.

Table 6.2 Average Anilox Configurations and Target Anilox Specifications

Ink	Screen count (lpi)[a]			Volume (BCM)[b]		
	Line (color)	Line (white)	Process	Line (color)	Line (white)	Process
Target Specifications	440	150	600 to 700	4 to 6	6 to 8	1.5
Solvent-based	350	260	650	5.5	6.8	2.1
Water-based	290	300	580	6.3	5.9	3.0
UV-cured	480	250	610	4.9	7.3	3.3

[a]lines per inch
[b]billion cubic microns per square inch

Uncertainties in Ink Component Weights

As discussed previously, the on-site observer collected information on the amounts of ink, solvents, additives, and cleaning solution added to or removed from the system during makeready, the press run, and clean-up. In some cases, however, site operating procedures, such as the type of cleaning system being used, prevented measurement of some of these parameters. In these cases, the weights were estimated based on other site data.

Ink and Press-side Solvent and Additive Consumption Estimates

Tables 6.3 and 6.4 present the average ink and and press-side solvent and additive consumption rates for the performance demonstration sites by ink type, substrate, and color. Site-specific consumption rates can be found in Tables 6-A.3 and 6-A.4 in Appendix 6-A.

In general, the UV-cured ink formulations used substantially less ink than the solvent-based or water-based formulations. On LDPE, the UV-cured ink systems used 57% less ink than the solvent-based ink systems and 28% less than the water-based ink systems. On PE/EVA, the UV-cured ink systems used 82% less ink than the solvent-based ink systems and 56% less than the water-based ink systems. These results are consistent with the general expectation that less UV-cured ink is needed because nearly all of the ingredients are incorporated into the dried coating, unlike with solvent- and water-based inks.

Components added to the water-based ink formulations included water, extender, solvent, ammonia, cross-linker, slow reducer, and defoamer. Components added to the solvent-based formulations were primarily solvents, but one company also added extender to the ink, whereas another added acetate. Water-based ink solvents and additives tended to comprise a smaller percentage of the overall total weight than did solvent-based ink solvents and additives. In the solvent-based systems, these additions accounted for about 25% of total consumption. No additives were used at the UV-cured ink demonstration sites, except for a low-viscosity monomer added to the green ink at Site 11.

Table 6.3 Average Ink and Press-side Solvent and Additive Consumption Rates for Performance Demonstrations (Pounds per 6,000 Images)

	Ink					Solvents and Additives			Sub-total: Ink	Sub-total: Solvents and Additives	Total
	Blue	Green	White[a]	Cyan	Magenta	Extender	Solvent	Additives			
Solvent-based ink											
LDPE	2.34	2.63	7.36	2.91	2.77	0.00	5.61	0.00	18.01	5.61	23.62
PE/EVA	2.34	2.63	0.00	2.91	2.77	0.00	3.78	0.00	10.65	3.78	14.43
OPP	1.36	1.55	7.86	1.37	1.25	0.16	4.44	0.78	13.39	5.38	18.77
Water-based ink											
LDPE	1.30	1.45	6.53	0.75	0.75	0.16	0.26	0.64	10.78	1.06	11.84
PE/EVA	1.30	1.45	0.00	0.75	0.75	0.00	0.06	0.37	4.25	0.43	4.68
OPP	1.30	1.09	6.79	0.59	0.60	0.19	0.17	0.08	10.37	0.44	10.81
UV-cured ink											
LDPE	0.94	0.73	5.18	0.37	0.48	0.00	0.00	0.01	7.71	0.01	7.72
PE/EVA	0.68	0.44	0.00	0.34	0.43	0.00	0.00	0.00	1.89	0.00	1.89
OPP	n/a[b]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[a]White ink was not printed on PE/EVA.
[b]n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

Table 6.4 Average Ink and Press-side Solvent and Additive Consumption Rates for Performance Demonstrations (Pounds per 6,000 Square Feet of Image)

	Ink					Solvents and Additives			Sub-total: Ink	Sub-total: Solvents and Additives	Total
	Blue	Green	White[a]	Cyan	Magenta	Extender	Solvent	Additives			
Solvent-based ink											
LDPE	1.05	1.18	3.31	1.31	1.27	0.00	2.52	0.00	8.12	2.52	10.64
PE/EVA	1.05	1.18	0.00	1.31	1.27	0.00	1.70	0.00	4.81	1.70	6.51
OPP	0.61	0.70	3.54	0.62	0.56	0.08	2.00	0.35	6.03	2.43	8.46
Water-based ink											
LDPE	0.58	0.65	2.94	0.34	0.34	0.07	0.12	0.28	4.85	0.47	5.32
PE/EVA	0.58	0.65	0.00	0.34	0.34	0.00	0.03	0.18	1.91	0.21	2.12
OPP	0.58	0.49	3.05	0.40	0.27	0.09	0.08	0.04	4.79	0.21	5.00
UV-cured ink											
LDPE	0.42	0.33	2.33	0.16	0.22	0.00	0.00	<0.01	3.46	0.00	3.46
PE/EVA	0.31	0.20	0.00	0.15	0.20	0.00	0.00	0.00	0.86	0.00	0.86
OPP	n/a[b]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[a]White ink was not printed on PE/EVA.
[b]n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

6.2 ENERGY CONSUMPTION

Energy conservation is an important goal for flexographic printers who strive to cut costs and seek to improve environmental performance. This section of the CTSA discusses the electricity and natural gas consumption rates of the flexographic printing equipment listed in Table 6.5, including background information and assumptions. Energy consumption rates are used in the cost analysis (Chapter 5) to calculate energy costs. They are also used in Section 6.3 to evaluate the life-cycle environmental impacts of energy consumption.

Table 6.5 Equipment Evaluated in the Energy Analysis

Equipment	Function	Ink system		
		Solvent-based	Water-based	UV-cured
Hot air drying system	Dries the ink between stations and in the overhead tunnel (main) dryer.	✔	✔	
Catalytic oxidizer[a]	Converts VOCs to carbon dioxide and water.	✔		
Corona treater	Increases the surface tension of the substrate to improve ink adhesion.		✔	✔
UV curing system	Cures UV-cured ink applied to substrate.			✔

[a]In some states, oxidizers may be required for water-based inks with high VOC content.

Energy estimates were to be prepared from the individual site data for each of the performance demonstration sites, similar to the site-specific ink consumption estimates presented in Section 6.1. However, limited or no energy data were available for one or more pieces of equipment at several of the sites, particularly for catalytic oxidizers used at solvent-based sites. In addition, press size, age, and condition of presses varied significantly across sites, as did equipment operating conditions, such as dryer temperature. For these reasons, equipment vendor estimates, rather than site-specific data, are used in the cost analysis to calculate energy costs.

Methodology

This section presents the methodology used to estimate energy requirements and provides background information and key assumptions on the types of equipment evaluated: hot air drying systems, catalytic oxidizers, corona treaters, and UV curing systems.

Energy Consumption

Equipment vendors estimated equipment energy requirements in kilowatts (kW) for electrical power and British thermal units (Btu) per hour for natural gas. This information was then converted into energy consumption rates for each ink type in Btus per 6,000 images and per 6,000 ft^2 of printed substrate. Table 6.6 lists the press, substrate, and image characteristics used in the energy estimates. These characteristics are consistent with assumptions used in the cost analysis and with the substrates and image printed during the on-site performance demonstrations. Where applicable, two sets of estimates were made: one using the project methodology press speed of 500 feet per minute (fpm) for all three ink types, and one using the average press speed achieved for each ink type at the performance demonstration facilities. Additional assumptions for each type of equipment and energy rate calculations are listed in the sections below.

Table 6.6 Press, Substrate, and Image Information for Estimating Energy Use

Parameter	Description	Comments
Press	48-inch, 6-color, CI press; new, average quality	Press costs are presented in Chapter 5.
Press speed	Solvent-based ink: 500 fpm and 453 fpm Water-based ink: 500 fpm and 394 fpm UV-cured ink: 500 fpm and 340 fpm	Two scenarios for each ink system are used in the corona treatment energy estimates.
Substrates	LDPE, PE/EVA, OPP	
Web width	20 inches	A second case assuming a 40-inch web was used in oxidizer and corona treater energy estimates.
Image size	16 in x 20 in (2.22 ft^2)	

Sample calculations based on the average press speed at water-based sites follow. Estimates were provided by equipment vendors.

Drying oven natural gas consumption = 500,000 Btu/hour
Blower electricity = 30 kW
Corona treater electricity = 1.6 kW
Total electricity = 31.6 kW
Average press speed (P) = 394 feet per minute
Image size = 2.22 ft^2
Image repeat (R) = 1.33 feet

Images printed per minute	= P/R
	= 394 feet per minute / 1.33 feet per image
	= 296 images/minute
	= 17,800 images/hour
Time to print 6,000 images	= 6,000 images / 17,800 images/hour
	= 0.34 hours
Natural gas per 6,000 images	= 500,000 Btu/hour × 0.34 hours
	= 170,000 Btu
Electricity per 6,000 images	= 31.6 kW × 0.34 hours
	= 11 kW-hr
Images per 6,000 ft^2	= 6,000 ft^2 / 2.22 ft^2 per image
	= 2,700 images
Time to print 6,000 ft^2	= 2,700 images / 17,800 images/hour

	= 0.15 hours
Natural gas per 6,000 ft^2	= 500,000 Btu/hour × 0.15 hours
	= 76,000 Btu
Electricity per 6,000 ft^2	= 31.6 kW × 0.15 hours
	= 4.7 kW-hr

Hot Air Drying Systems

Most solvent-based and water-based presses are equipped with between-color (interstation) dryers (BCDs) and an overhead (main) dryer. Supply and exhaust blowers are used to provide air flow through the dryers and maintain negative pressure within the dryer. The supply blowers draw air into the drying system to be heated by the burners. Most printers draw the dryer make-up air from the ambient environment outside the plant.[1] Exhaust blowers are used to draw the heated air though the dryers to the exhaust outlet.

The BCDs are positioned after each print station. They dry each color as it is applied to the web to prevent pick-up or tracking when the next color is applied. The overhead dryer consists of a tunnel located above the print stations, through which the web passes to further dry the ink before the web is rewound.

The energy consumed by hot air drying systems includes electrical power for the supply and exhaust blowers and natural gas for the drying oven. Typically, the gas energy required to heat the process air is greater than the energy needed to dry the ink.[2]

Kidder, Inc., a press manufacturer, provided energy estimates for hot air drying systems based on the press, substrate, and image details listed in Table 6.6, the average ink consumption rates listed in Table 6.3, and the hot air drying system assumptions listed in Table 6.7. Dryer energy estimates for both solvent- and water-based inks are based on the same air flow rates but different dryer temperatures. New presses are now designed to work with either water-based or solvent-based inks. Usually, a press operator will reduce the amount of heat instead of the air flow when using solvent-based inks.[3] Air flow rates are given in units of cubic feet per minute (cfm).

Table 6.7 Hot Air Drying System Assumptions

Parameter	Assumption	Comments
BCD air flow rate	2800 cfm	Four dryer boxes at 700 cfm/box, based on average BCD flow rate of 15 cfm/inch of width/dryer box[a]
Main dryer air flow rate	3000 cfm	Typical value for 48-inch press[a]
Dryer temperature (solvent-based Inks)	150°F	Typical temperature for Project substrates[a]
Dryer temperature (water-based inks)	200°F	Typical temperature for Project substrates[a]
Make-up (outdoor) air temperature	0°F, 50°F, 70°F	Three scenarios
Percent recirculation of dryer air	0%, 50%	Two scenarios

cfm = cubic feet per minute.

[a] Reference 4.

The assumed dryer temperature for water-based inks is higher than the maximum temperature to which some film substrates can be subjected without potentially damaging the film. However, in practice, the film temperature would be less than the dryer temperature due to impression cylinder cooling and evaporative cooling.[5]

The hot air drying system energy estimates were prepared for six different operating scenarios, assuming three different outside air temperatures for the make-up air and two dryer air recirculation scenarios (no recirculation and 50% recirculation). All six scenarios were analyzed to illustrate the influence make-up air temperature and air recirculation on dryer costs. The different air temperatures represent the range of air temperatures that might be encountered in different seasons. If make-up air is taken from the outdoor environment (as is typically done), dryer costs will be significantly higher in winter than in summer. The 50°F temperature was used in the cost analysis to represent an annual average. Most new presses are designed to recirculate dryer air, either to save on dryer air heating costs or to reduce the air flow to the pollution control device.[6] However, many older presses do not have dryer air recirculation, and retrofitting may be ineffective with smaller, low air flow presses. A recirculation rate of 50% was used in the cost analysis since this is more representative of a new press, the subject of the cost analysis.

Catalytic Oxidizers

A catalytic oxidizer is a type of add-on emissions control equipment used to convert VOC emissions to carbon dioxide and water by high temperature oxidation. Catalytic incinerators employ a catalyst bed to facilitate the overall combustion reaction by increasing the reaction rate. This enables conversion at lower reaction temperatures than in thermal oxidizers. Oxidizers are used primarily with solvent-based inks, but may be required with water-based inks in some states.

A basic catalytic oxidizer assembly consists of a heat exchanger, a burner, and a catalyst. First, the dryer exhaust stream is preheated by heat exchange with the oxidizer effluent and, where necessary, further heated to the desired catalyst inlet temperature by a natural gas-fired burner. The heated stream then passes through the catalyst where VOCs are converted to carbon dioxide and water. The combustion reaction between oxygen and gaseous pollutants in the waste stream occurs at the catalyst surface. The oxidizer effluent is then recirculated back to the heat exchanger and may also be recirculated to the dryer to save drying fuel.

Two oxidizer suppliers, Anguil Environmental Systems, Inc. and MEGTEC Systems [formerly Wolverine (Massachusetts) Corporation], provided energy estimates based on the press, substrate, and image details listed in Table 6.6 and the additional oxidizer assumptions presented in Table 6.8.[7] As with the other equipment, the oxidizer energy estimates represent energy requirements for a particular set of circumstances (e.g., solvent loading, dryer exhaust temperature, flow rate), and they are not necessarily representative of other operating conditions.

Table 6.8 Catalytic Oxidizer Assumptions

Parameter	Assumption	Comments
Number of presses vented to oxidizer	Two	
Solvent content	13,000 Btu/lb	Average of typical values provided by two oxidizer suppliers
Heat exchanger efficiency	70%	Typical efficiency value based on vendor input. Equipment vendors also provided oxidizer energy estimates for 65%, 75%, and 80% efficiencies.
Air flow to oxidizer	5800 cfm	Combined air flow after recirculation for two 48-inch presses; same as air flow used in dryer energy estimates
Dryer exhaust temperature	150°F	Dryer temperature assumed for drying oven energy calculations
Catalyst inlet temperature	600°F	Depending on solvent type, catalyst inlet temperatures can vary from 475°F to 650°F [8,9,10,11,a]
Solvent loading (two cases)	70 lb/hr 140 lb/hr	Solvent loading for two presses; solvent loading at performance demonstration sites averaged 35 lb/hr for one press. Solvent loading assuming each 48-inch press is running two 20-inch images, side by side (i.e., solvent loading for a 40-inch web width).

The catalytic oxidizer energy estimates were prepared assuming two different solvent loadings (70 and 140 lb/hr). The solvent loadings were based on two web widths (20-inch and 40-inch). A solvent loading of 70 lb/hr was used in the cost analysis.

[a] Technology developments are allowing for decreased catalyst inlet temperatures. A published estimate notes that a typical catalyst inlet temperature is 550-700°F. Another industry estimate notes that with solvent loading, the typical temperature can rise to 650°F. However, some new oxidizers are capable of operating at 500°F.

Two scenarios for solvent loading are provided because it would be very unusual for a facility with a 48-inch press to run a 20-inch image, which reduces solvent loading to the oxidizer. Oxidizer energy costs decrease with increased solvent loading until the oxidation reaction becomes self-sustaining (e.g., requires no make-up fuel). Using a 20-inch image on a 48-inch press and the associated lower solvent loading would tend to overestimate energy costs. Solvent loading of 140 lb/hr portrays a more realistic situation, in which two 20-inch images are run side by side on a 48-inch press.

A heat exchanger efficiency of 70%, a typical efficiency, was used in the cost analysis. The other values (65%, 75%, and 80%) were submitted by oxidizer vendors to illustrate the effect of heat exchanger efficiency on oxidizer energy costs.

Corona Treaters

Corona treatment is a process that increases the surface energy of a substrate to improve ink adhesion. It can be performed three ways: by the substrate supplier, when the substrate is on the printing press, or both by the substrate supplier and on press. On-press corona treatment systems may be used with all three ink types, but are mainly used with water-based and UV-cured inks, which typically have lower surface energy than solvent inks. None of the performance demonstration sites running solvent-based inks used corona treatment on the press.

A corona treatment assembly consists of a power supply and treater station. The power supply accepts standard utility electrical power and converts it into a single-phase, higher-frequency power that is supplied to the treater station. The treater station applies the higher frequency power to the surface of the material via a pair of electrodes.[12]

The energy consumed by a corona treatment system can depend on a number of factors, including web width, production speed, type of substrate (e.g., material, slip additives), and watt density (watts per unit area per unit time) required to treat the substrate. Table 6.6 presents press, substrate, and image details. Enercon Industries Corporation, a corona treater supplier, provided corona treatment energy estimates, including the power supply size and input power. Input power represents the actual power drawn from the utility grid. Watt density was not specified, so the equipment suppliers determined the appropriate watt density.

UV Curing Systems

UV presses employ UV lamps, which emit UV radiation to polymerize or cross-link the UV-cured ink monomers. In addition to the lamps, a UV curing system has supplemental cooling capacity to counter the infrared heat produced by the UV lamps. The curing system may also include a blower to extract ozone generated during the UV curing process, and an anilox heater to pre-heat the ink. Only one of the three UV performance demonstration sites had a separate ozone blower and anilox heater.

Energy estimates for UV curing systems were developed based on operating data collected during the performance demonstrations; supplemental information from Windmöller & Hölscher, an equipment supplier; and information from another equipment supplier, Fischer & Krecke, Inc. Table 6.9 presents the UV curing system assumptions. Lamp output is assumed to be constant at both press speeds evaluated (i.e., at 500 fpm and 340 fpm). However, in most UV systems lamp power increases with press speed up to some maximum power output level, depending on the press. For example, lamp output provided by one press manufacturer ranged from 48 watts per centimeter of press width (W/cm) at a press speed of 100 fpm to 160 W/cm at 820 fpm.[13] In another example, manufacturer data for lamp output at a performance demonstration site ranged from 80 w/cm at standby to 200 w/cm at 200 fpm. No data were available to accurately account for the differences in lamp output at the two project press speeds. Lamp energy in watts was calculated by multiplying the lamp output in watts per inch by the press width (48 inches) and by the total number of lamps (six).

Table 6.9 UV Curing System Assumptions

Parameter	Assumption	Comments
Lamp output	175 watts per cm of press width	Average value based on site and vendor data
Number of lamps	Six	Four lamps between colors and two main lamps
Lamp cooling	60 kW	Average value based on site data and vendor data

Limitations and Uncertainties

The limitations of and uncertainties in the energy analysis stem from the lack of energy data at many of the demonstration sites, the limitations in the number of operating scenarios evaluated, limitations in the data for different press speeds, and uncertainties inherent in using estimated data rather than measured data. Each of these limitations is discussed below.

Lack of Energy Data at Performance Demonstration Sites

The performance demonstration methodology called for energy data collection at the 11 performance demonstration sites in order to develop a "snapshot" of energy requirements under actual operating conditions at a limited number of facilities. As discussed previously, little or no energy data were available for one or more pieces of equipment at several of the sites, particularly for catalytic oxidizers used at solvent-based sites. In addition, press size, age, and condition varied significantly across sites, as did equipment operating conditions, such as dryer temperature. For these reasons, equipment vendor estimates, rather than site-specific data, are the focus of the energy analysis. As a result, the data are estimated based on hypothetical operating conditions and do not necessarily represent energy demand experienced at the performance demonstration sites.

Limitations in the Number of Operating Scenarios

The operating conditions and assumptions used in the energy analysis were developed based on the test image, substrates, and operating conditions at the performance demonstration sites, as well as using typical operating conditions provided by equipment vendors. As such, the energy estimates represent a "snapshot" of equipment energy requirements under a particular set of conditions. They are not necessarily indicative of the range of energy requirements that might be experienced for different images, substrates and operating conditions, nor are they intended to represent this range.

Limitations in the Data for Different Press Speeds

The energy consumed by printing equipment is often a direct or indirect function of press speed. For example, the power outputs of UV lamps and corona treaters usually vary directly with the press speed. The amount of make-up fuel required for a catalytic oxidizer depends on the solvent loading, which varies with the ink, image, and press speed, among other factors. However, except for corona treaters, no quantitative data were available to determine the differences in equipment energy draw at the different project press speeds (e.g., the average press speeds observed at performance demonstration sites and the methodology press speed of 500 fpm). This can result in either an overestimation of energy requirements at the lower press speeds or an underestimation of energy requirements at the higher press speeds.

Uncertainties in Estimated Data

Equipment energy requirements were estimated by equipment vendors for use in the cost analysis. Attempts were made to get estimates from at least two vendors for each type of equipment, but in some cases only one estimate was available. Vendor energy estimates were compared to each other, to performance demonstration data, and to other data sources as available, to check for reasonableness and completeness. Either averages or the most complete and representative data are presented in the results below and used in the cost analysis.

Energy Consumption Estimates

Table 6.10 presents the equipment vendor energy estimates used to develop energy consumption rates. Table 6.11 presents gas and electrical energy consumption rates in Btus. Results from the latter table were used in the cost analysis (Chapter 5). The energy consumption results for each type of equipment across the three ink systems are discussed in more detail in the following sections. For the estimated energy costs for each ink system and substrate combination, see Table 5.17 in the Cost chapter.

Under the particular operating parameters and assumptions used in this analysis, the water-based system consumed the least energy at both press speeds. UV energy consumption rates were most influenced by the press speed, due to the lower average press speed achieved at UV performance demonstration sites. However, as noted previously, no data were available to account for the lower lamp energy draw that can occur at lower press speeds. Solvent-based systems have lower drying energy requirements than water-based, but have higher overall energy requirements when the oxidizer energy requirements are taken into account. These results would be reversed (e.g., water-based inks would require more energy than solvent-based inks) if the solvent-loading to the oxidizer was sufficient to make the oxidizer self-sustaining and/or recirculation of dryer air was not taken into account for water-based systems.

The results of the energy analysis in Table 6.11 can be compared to a similar analysis of energy consumption undertaken by a press manufacturer that supplies both hot air and UV cured systems.[14] That study evaluated the relative energy consumption of a 55-inch press running the different ink systems. Table 6.12 shows the results of that analysis, which suggest that solvent-based and water-based systems have roughly the same energy requirements if pollution control equipment is required for both ink types, while UV-cured inks have slightly greater energy requirements.

Table 6.10 Equipment Vendor Energy Estimates Used to Develop Consumption Rates

Ink	Equipment	Natural gas (Btu/hr)	Electricity (kW)	Comments
Solvent-based	Drying oven	360,000	n/a[a]	Based on an outdoor air temperature of 50ºF and 50% recirculation of dryer air
	Dryer blowers	n/a	30	Average of values recommended in dryer energy audits from some performance demonstration sites and by equipment vendor
	Oxidizer	290,000	n/a	Average of values from two equipment vendors; based on 70 lb/hr solvent loading
	Oxidizer blower	n/a	25	Average of values from two equipment vendors
Water-based	Drying oven	500,000	n/a	Based on an outdoor air temperature of 50ºF and 50% recirculation of dryer air
	Dryer blowers	n/a	30	Average of values recommended by two performance demonstration sites and by equipment vendor
	Corona treater	n/a	2.1, 1.6	Based on worst case substrate (PE/EVA) running at 500 and 394 fpm, respectively
UV-cured	UV lamps	n/a	130	See Table 6.9 for basis
	Lamp cooling	n/a	60	See Table 6.9 for basis
	Corona treater	n/a	2.1, 1.6	Based on worst case substrate (PE/EVA) running at 500 and 394 fpm, respectively

[a]n/a: not applicable

Table 6.11 Average Energy Consumption Rates for Each Ink System

Ink	Press speed (fpm)	Energy per 6,000 images (Btu)[a]	Energy per 6,000 ft^2 of image (Btu)[a]
Solvent-based	500	220,000	100,000
	453[b]	240,000	110,000
Water-based	500	160,000	73,000
	394[b]	220,000	96,000
UV-cured	500	174,000	78,000
	340[b]	260,000	120,000

[a]Electrical energy was converted to Btus using the factor of 3,413 Btu per kW-hr.
[b]Average press speed for the performance demonstration sites.

Table 6.12 Energy Consumption per Job by Ink Type[a]

Equipment	Energy consumption by ink type (Btu/hr)		
	Solvent-based	Water-based	UV-cured
Dryer[b]	≈310,000	≈310,000	n/a[c]
Pollution control[b]	≈200,000	(200,000)[d]	n/a
Corona treatment	n/a	17,000	≈17,000
UV lamps	n/a	n/a	≈550,000
Temperature conditioning	n/a	n/a	≈85,000
Driving motors/pumps	≈200,000	≈200,000	≈200,000
Total	≈710,000	530,000-730,000	≈850,000

[a]Source: Reference 15. Source did not specify the type or length of job evaluated.
[b]Heater plus blower
[c]n/a: not applicable
[d]Pollution control may or may not be required with water-based inks.

Hot Air Drying Systems

As discussed previously, six scenarios were evaluated for the natural gas requirements of a hot air drying system, based on three different ambient air temperatures and the presence or absence of dryer air recirculation. Table 6.13 presents the results of these analyses. The energy requirements for hot air drying systems were calculated using a proprietary formula that considers make-up air temperature, dryer temperature, and air flow.[16] As shown in the table, recirculation can greatly reduce energy load. There are many factors involved, but in this scenario dryer energy with recirculation can be calculated assuming a relationship of 40% fuel savings for 60% recirculation.[17] Whenever recirculating air is used with solvent-based inks, however, it is imperative that the lower explosive limit (LEL) be monitored and controlled to safe limits.[18]

Table 6.13 Natural Gas Energy Estimates for Hot Air Drying Systems

Ambient air temperature (°F)	Percent air recirculation (%)	Natural gas energy (Btu/hr)	
		Solvent-based	Water-based
0	0	720,000	890,000
0	50	480,000	600,000
50	0	530,000	740,000
50	50	360,000	500,000
70	0	440,000	670,000
70	50	290,000	450,000

Source: Reference 19.

Dryer gas energy data collected during the performance demonstrations were largely incomplete. Data that were collected varied widely due to differences in press sizes and operating conditions. For example, gas energy data were only available from four of eight sites (one of which ran both solvent- and water-based ink systems) and ranged from gas burner capacity data to energy estimates from dryer energy audits. The average gas consumption rates reported by solvent-based and water-based sites were 2.4 million Btus/hr and 1.5 million Btus/hr, respectively. These values are significantly higher than the values estimated in Tables 6.10 and 6.13. Differences may be attributed in part to the larger press sizes at these sites (average 54 inches), press age, dryer temperatures and flow rates, and the amount of dryer air recirculation.

Catalytic Oxidizers

Oxidizer vendors were asked to estimate oxidizer energy requirements for two scenarios using the assumptions in Table 6.8: The first scenario is two 48-inch presses running the performance demonstration image vented to the same oxidizer (70 lb/hr solvent loading). The second scenario is two presses fully loaded with two performance demonstration images (140 lb/hr solvent loading). The first scenario is consistent with assumptions used in the cost analysis (Chapter 5) and was used to generate the energy consumption rates in Tables 6.10 and 6.11. The second scenario illustrates the effect of solvent loading on energy requirements. In general, as solvent loading increases, natural gas energy decreases until the solvent loading is sufficient to make the reaction self-sustaining.

In addition to the two scenarios described above, the oxidizer vendors prepared energy estimates based on heat exchanger efficiencies of 65%, 70%, 75%, and 80%. Table 6.14 presents the catalytic oxidizer energy estimates for the various solvent loadings and heat exchanger efficiencies and the specific assumptions in Table 6.8. Other operating parameters that can significantly affect the overall energy requirements of an oxidizer include the solvent heat content, the air flow to the oxidizer, and the inlet air temperature.

Table 6.14 Catalytic Oxidizer Energy Estimates[a]

Solvent loading	Equipment	Energy estimates by heat exchanger efficiency				
		65%[b]	70%[b]	70%[c]	75%[c]	80%[c]
70 lb/hr	Burner (Btu/hr)	560,000	260,000	320,000	130,000	70,000
	Damper/blower (kW)[d]	17[e]	17[e]	32[f]	32[f]	32[f]
140 lb/hr	Burner (Btu/hr)	16,000	16,000	70,000	n/a[g]	n/a
	Damper/blower (kW)[d]	17[e]	17[e]	32[f]	n/a	n/a

[a]Energy estimates are based on the assumptions in Table 6.8 plus additional assumptions made by equipment vendors. Values do not necessarily represent the relative energy efficiency of the vendor's equipment.

[b]Source: Reference 20.

[c]Source: Reference 21.

[d]One kW-hr = 3,413 Btu

[e]Based on 22 hp blower

[f]Based on 40 hp motor with volume blower

[g]n/a: not applicable, unit is at minimum Btu/hr usage with another heat exchanger.

Corona Treaters

Corona treatment energy requirements were estimated for two press speeds (500 fpm and the performance demonstration site averages) and two web widths (20 inch and 40 inch). One corona treater supplier provided power supply and input power estimates for the worst case substrate (2.5 mil PE/EVA, high slip) only, while the other provided watt density and power supply data for all of the substrates, but did not provide input power estimates. Because the remainder of the energy analysis is based on input power rather than power supply, estimates provided by the first supplier were used to generate the results in Tables 6.10 and 6.11. Table 6.15 lists corona treater energy estimates for a 500 fpm press speed. Table 6.16 lists corona treater energy estimates for the average press speed at the performance demonstration sites.

Table 6.15 Corona Treater Energy Estimates (Press Speed of 500 Feet per Minute)

Ink	Substrate	Watt density (watts/m^2/min)		Power supply (kW)				Input power (kW)	
		20" web[a]	40" web[a]	20" web[a]	40" web[a]	20" web[b]	40" web[b]	20" web[b]	40" web[b]
Water-based	LDPE	3,100	6,200	3.0	7.5	ND[c]	ND	ND	ND
	PE/EVA	3,100	6,200	3.0	7.5	2.0	3.5	2.1	3.6
	OPP	3,100	6,200	3.0	7.5	ND	ND	ND	ND
UV-cured	LDPE	3,100	6,200	3.0	7.5	ND	ND	ND	ND
	LDPE (no slip)	2,300	4,600	3.0	5.0	ND	ND	ND	ND
	PE/EVA	3,100	6,200	3.0	7.5	2.0	3.5	2.1	3.6
	OPP	3,100	6,200	3.0	7.5	ND	ND	ND	ND

[a]Source: Reference 22.
[b]Source: Reference 23.
[c]ND = no data

Table 6.16 Corona Treater Energy Estimates (Average Press Speeds at the Performance Demonstration Sites)

Ink	Substrate	Watt density (watts/m^2/min)		Power supply (kW)				Input power (kW)	
		20" web[a]	40" web[a]	20" web[a]	40" web[a]	20" web[b]	40" web[b]	20" web[b]	40" web[b]
Water-based	LDPE	2,400	4,700	3.0	5.0	ND[c]	ND	ND	ND
	PE/EVA	2,400	4,700	3.0	5.0	1.5	3.0	1.6	3.1
	OPP	2,400	4,700	3.0	5.0	ND	ND	ND	ND
UV-cured	LDPE	2,100	4,200	3.0	5.0	ND	ND	ND	ND
	LDPE (no slip)	1,600	3,100	1.5	3.0	ND	ND	ND	ND
	PE/EVA	2,100	4,200	3.0	5.0	1.5	2.5	1.6	2.6
	OPP	2,100	4,200	3.0	5.0	ND	ND	ND	ND

[a]Source: Reference 24.
[b]Source: Reference 25.
[c]ND = no data

Table 6.17 presents power output data (e.g., power applied to the web) read by WMU representatives from the corona treater power supply box during the performance demonstration runs. In some cases, WMU representatives also measured power input in volts and amps during the print run. However, these data are not reported because corona treater suppliers have indicated they cannot be used to calculate power input in kilowatts without knowing site-specific power efficiency factors.[26]

Table 6.17 Corona Treater Power Output at Performance Demonstration Sites

Ink	Substrate	Site	Power output (kW)	
			Makeready	Print run
Water-based	OPP	1	6.4	ND[a]
	LDPE, PE/EVA	2	1.9	ND
	LDPE, PE/EVA	3	4.0	4.0
	OPP	4	3.0	3.0
	OPP	9A	ND	ND
UV-cured	OPP, LDPE, PE/EVA	6	11.0	ND
	OPP, LDPE, PE/EVA	8	2.2	ND
	LDPE (no slip)	11	n/a[b]	n/a

[a]ND: no data
[b]n/a: not applicable; Site 11 did not have a corona treater.

UV Curing Systems

Lamp energy estimates for either press speed were obtained at 160 watts/cm of press width, 174 watts/cm, and 185 watts/cm. Larger differences were seen in the supplemental lamp cooling estimates, which ranged from 25 kW to 90 kW. The smaller value is for a water-cooled system; reportedly, most UV lamp systems are air-cooled.[27]

6.3 ENVIRONMENTAL IMPACTS OF ENERGY REQUIREMENTS

The energy requirements of the solvent-based, water-based and UV ink systems presented in Section 6.3 result in energy costs to printers (see Chapter 5, Cost). Environmental releases from energy production also result in indirect costs to society. Examples of the types of air emissions released during energy production include carbon dioxide (CO_2), sulfur oxides (SO_x), carbon monoxide (CO), sulfuric acid (H_2SO_4), and particulate matter. The potential environmental and human health impacts of these releases include health effects to humans and wildlife, global warming, acid rain, and photochemical smog. For more information on the potential impacts of printing on society, see Chapter 8, Choosing Among Ink Technologies.

This section quantifies the types and amounts of emissions released into the environment from energy production and discusses the potential environmental impacts of the releases. For electrical energy, emissions are typically released at electrical power plants outside the printing facility. Releases from natural gas combustion may occur at the print shop where the combustion process occurs.

Emissions from Energy Production

Energy-related emissions — both at and away from the facility — can be a significant part of the total life-cycle environmental impact of printing. Emissions are released from natural gas-burning dryers and oxidizers as well as from the electricity generation process at offsite power plants. The level of emissions can vary considerably among printing technologies, depending on the fuel type and process efficiency.

The emissions from energy production during the performance demonstrations were evaluated using a computer program developed by the EPA National Risk Management Research Laboratory.[28] This program, which is called *P2P-version 1.50214,* can estimate the type and quantity of releases resulting from the production of energy, as long as the differences in energy consumption and the source of the energy used (e.g., hydro-electric, coal, natural gas, etc.) are known. The program compares the pollution generated by different processes (e.g., extraction and processing of coal or natural gas for fuel).

Electrical power derived from the average national power grid was selected as the source of electrical energy, and natural gas was used as the source of thermal energy for this evaluation. Energy consumption rates per 6,000 ft^2 from Table 6.11 were used as the basis for the analysis. It should be noted that the location of the environmental impacts will vary by energy type; natural gas releases will occur onsite, while electricity-related releases will occur at offsite power plants.

Results of this analysis are presented in Table 6.18. Appendix 6-C contains printouts from the P2P program. Water-based systems generally had the lowest levels of emissions from energy production at either press speed, followed by solvent-based systems. The releases associated with the production of energy for the UV ink system exceeded those from water-based or solvent-based systems for every pollutant category except hydrocarbons. Hydrocarbon emissions were greater for the water-based and solvent-based systems, because of the natural gas consumed by the hot-air dryers used with these systems. Greater emissions from energy production were seen at lower press speeds for all of the systems, due to the longer run times needed to print a given quantity of substrate. However, as noted in Section 6.2, data were not available for all equipment to estimate the differences in energy draw at different press speeds. Emissions from energy production would be reduced if equipment powers down at decreased press speeds.

Table 6.18 Releases Due to Energy Production[a]

Ink System	Press Speed (fpm)	Amount Released (g/6,000 ft^2)								
		Carbon Dioxide (CO_2)	Carbon Monoxide (CO)	Dissolved Solids	Hydrocarbons	Nitrogen Oxides (NO_x)	Particulates	Solid Wastes	Sulfur Oxides (SO_x)	Sulfuric Acid (H_2SO_4)
Solvent-based	500	9,400	8.7	1.3	55	26	8.0	570	44	3.4
	453	10,000	9.6	1.4	60	29	8.8	630	48	3.8
Water-based	500	6,400	5.5	0.81	41	16	4.8	340	26	2.0
	394	8,000	6.8	1.0	52	20	5.9	410	33	2.5
UV-cured	500	16,000	23	3.0	20	70	27	2,000	140	12
	340	24,000	33	4.5	29	100	40	2,900	210	17

[a]Releases for solvent- and water-based ink systems are expected to occur both at the printing facility and at the off-site electricity generation plant; releases from the UV-cured ink system are expected to occur exclusively at the electricity generation plant.

The higher overall emissions for UV systems were due primarily to the differences in fuel mixes used by the three systems (both electrical and natural gas energy for water-based and solvent-based systems, as compared to electrical energy alone for UV). The U.S. electric grid is mainly comprised of coal, nuclear, hydroelectric, gas and petroleum-fired power plants. In 1997 the majority of U.S. electrical energy (57%) was produced from coal-fired generators,[29] which tend to release greater quantities of emissions than gas-fired energy systems. For example, at a 500 fpm press speed, the UV system consumed an estimated 23 kW-hr /6,000ft^2 of electricity, which is equivalent to 78,000 Btu/6,000ft^2. At the same press speed, the solvent-based system consumed an estimated 6.6 kW-hr/6,000ft^2 of electricity plus 78,000 Btu/6,000ft^2 of natural gas, for a total of 100,000 Btu/6,000ft^2 . However, although the UV system consumed less overall energy than the solvent-based system, it still had higher emissions from energy production for the pollutants evaluated, except hydrocarbons.

Environmental Impacts of Energy Production

Table 6.19 lists the pollution categories, pollutant classes, and media of release assigned by the P2P software. Table 6.20 lists total pollution generated by pollutant category and class, and Table 6.21 provides totals for each pollution category.

Based on the release rates shown in Tables 6.21 and 6.22, the water-based systems showed the lowest potential environmental impacts from energy production, including human health, use impairment, or disposal capacity impacts, followed by solvent-based systems. The UV systems had the greatest potential environmental impacts from energy production in each of the pollution categories and classes.

Limitations and Uncertainties

These release rates can only be used as *indicators* of relative potential impacts, not as an assessment of risk. Assessing risk from energy production also would require knowledge of the location and concentration of release, and proximity to surrounding populations. It would also require more information on the specific chemicals emitted, for example the exact identity of the hydrocarbons emitted during natural gas combustion as compared to the hydrocarbons emitted during coal combustion.

The potential environmental impacts of energy requirements for the three ink systems are based on the energy estimates described in Section 6.2 and are subject to the same limitations and uncertainties.

Table 6.19 Pollution Categories, Classes and Media of Release

Pollution Category	Pollutant Class	Chemicals	Affected Resource
Human Health Impacts	Toxic Inorganics[a]	Nitrogen oxides, sulfur oxides	Air
	Toxic Organics[a]	Carbon monoxide	Air
Use Impairment Impacts	Acid Rain Precursors	Nitrogen oxides, sulfur oxides	Air
	Corrosives	Nitrogen oxides, sulfur oxides	Air
		Sulfuric acid	Water
	Dissolved Solids[b]	Dissolved solids, sulfuric acid	Water
	Global Warmers	Carbon dioxide, nitrogen oxides	Air
	Odorants	Hydrocarbons	Air
	Particulates[c]	Particulates	Air
	Smog formers	Carbon monoxide, hydrocarbons, nitrogen oxides	Air
Disposal Capacity Impacts	Solid Wastes	Solid Wastes	Soil, groundwater

[a] Dissolved solids are a measure of water purity and can negatively affect aquatic life as well as the future use of the water.
[b] Toxic organic and inorganic pollutants can cause adverse health effects in humans and wildlife.
[c] Particulate releases can promote respiratory illness in humans.

The program uses data reflecting the national average pollution releases per kilowatt-hour derived from particular sources. It does not account for differences in emission rates at different power plants, nor does it necessarily account for the latest in pollution control technologies applied to power plant emissions.

The P2P program primarily accounts for emissions of pollutant categories and not emissions of the individual chemicals or materials known to occur from energy production, such as mercury. Nor does it provide information on the spatial or temporal characteristics of releases. Thus, the P2P software provides emissions estimates in grams per functional unit (grams per 6,000ft^2 of printed surface, in this case) and assigns them to pollution (impact) categories and classes to develop release rates by impact category. As discussed previously, these release rates can be used as an *indicator* of relative potential environmental impacts, but are not an assessment of risk.

Table 6.20 Emissions Generated by Pollutant Category and Class

Pollution Category	Pollutant Class	Emissions Generated by Pollutant Category and Class[a] (g/per 6,000ft^2)					
		Solvent (500 fpm)	Solvent (453 fpm)	Water (500 fpm)	Water (394 fpm)	UV (500 fpm)	UV (340 fpm)
Human Health Impacts	Toxic Inorganics	70	77	43	53	210	310
	Toxic Organics	8.7	9.6	5.5	6.8	23	33
Use Impairment Impacts	Acid Rain Precursors	70	77	43	53	210	310
	Corrosives	73	81	45	56	220	330
	Dissolved Solids	4.7	5.2	2.8	3.5	15	22
	Global Warmers	9,400	10,000	6,400	8,000	16,000	24,000
	Odorants	55	60	41	52	20	29
	Particulates	8.0	8.8	4.8	5.9	27	40
	Smog formers	90	99	63	79	110	170
Disposal Capacity Impacts	Solid Wastes	570	630	340	410	2,000	2,900

[a] All numbers have been rounded to two significant figures.

Table 6.21 Summary of Pollution Generated by Category

Pollution Category	Pollution Generated [a] (g/per 6,000ft^2)					
	Solvent (500 fpm)	Solvent (453 fpm)	Water (500 fpm)	Water (394 fpm)	UV (500 fpm)	UV (340 fpm)
Human Health Impacts	79	87	48	60	230	350
Use Impairment Impacts	9,500	10,000	6,500	8,100	16,000	24,000
Disposal Capacity Impacts	570	630	340	410	2,000	2,900
Overall Environment	10,000	11,000	6,800	8,500	18,000	27,000

[a] All numbers have been rounded to two significant figures.

6.4 CLEAN-UP AND WASTE DISPOSAL PROCEDURES

This section of Chapter 6 discusses the types of cleaning solutions and clean-up methods used for the three different flexographic ink technologies studied in the CTSA performance demonstrations, and describes the disposal procedures for the various types of wastes generated in each case.

All flexographic printing operations result in waste ink and substrate, soiled shop towels, and cleaning solutions that need to be disposed. However, the volume of waste ink and the specific chemical makeup of wastes differ, depending on the type of ink system that a printer uses. Therefore, the clean-up methods, waste disposal procedures, and overall environmental impacts of a printing process also differ for each ink system.

Most printers employ the same basic procedures to clean solvent-based or water-based ink from a press. Excess ink may be wiped or scraped down and drained from the press. The system is then flushed with a cleaning solution to remove additional ink and prepare the press for a fresh run. Shop towels, usually wetted with a cleaner, are used to wipe down the anilox rolls, doctor blades, or other press parts. UV ink cleaning procedures are similar, except that different cleaners or dry shop towels may be used to wipe down the press.

Most solvent-based ink wastes are classified as hazardous waste and are disposed of accordingly. Water-based ink wastes, however, may or may not be classified as hazardous waste. Although solvent-based waste disposal costs may be reduced because it can be burned and used for heat production, this is not always possible with water-based wastes. Regulations prohibit hazardous waste from being mixed with fuel and burned if it has an energy value of less than 5,000 Btu/lb.[30] Therefore, some printers using low-solvent water-based inks use an "ink splitter" to separate the solids from fluids in their waste ink and cleaning solutions. This substantially reduces the amount of hazardous waste that needs to be disposed. The waste water usually can be reused in-house or discharged to the public water system, but if the original waste qualified as hazardous, the solids also will need to be treated as hazardous waste. (See the Control Options section of Chapter 7 for more information on ink splitters.)

Multi-day runs of UV-cured printing may generate less ink waste than solvent-based or water-based printing for printers who shut down overnight, such as some smaller printers. In this case, the ink can remain indefinitely on the press or in the reservoirs without curing on press parts or the sump.[31] The press is shut down, the ink reservoirs should be covered to prevent dust from getting in, and the press is turned on to resume printing the next day. Also, because correct color adjustment is achieved more quickly at the beginning of a UV run using process colors on dedicated stations, under these conditions UV may generate somewhat less waste of ink and substrate. However, because UV inks are too thick to be modified easily, correct color adjustment may not be achieved more quickly when using matched/Pantone colors that require toning.[32]

Press Clean-Up and Waste Reduction in the CTSA Performance Demonstrations

Table 6.22 summarizes the types of cleaning solutions used at the performance demonstration sites. For solvent-based systems, three sites utilized a blend of alcohol and acetate solutions, and one site reported using alcohol alone. The cleaning solutions used for UV-systems were the same as those for solvent-based systems, except for one site that used an alcohol/water/soap blend. Water, at times mixed with a little alcohol and/or ammonia, was used for clean-up of the water-based ink systems.

Table 6.22 Cleaning Solutions Used at Performance Demonstration Sites

Ink System	Cleaning Solution
Solvent-based	Alcohol/acetate blend (3 sites) Alcohol (1 site)
Water-based	Water only (2 sites) Water/alcohol blend (1 site) Water/ammonia blend (1 site) Water/ammonia/alcohol blend (1 site)
UV-cured	Alcohol (1 site) Alcohol/acetate blend (1 site) Alcohol/water/soap blend (1 site)

The clean-up and waste disposal procedures employed at the performance demonstration sites are summarized in Table 6.23. Appendix 6-B describes these procedures in more detail. All but one site employed reusable shop towels to clean the press. All sites recycled some or all of their waste substrate.

Table 6.23 Clean-up and Waste Disposal Procedures at Performance Demonstration Sites

Ink System	Shop Towels	Ink and Cleaning Solution Disposition	Waste Substrate Disposition
Solvent-based	Sent to industrial laundry (3 sites) Landfilled (1 site)	Solvent mix to cement kiln (1 site) On-site distillation; still bottoms to cement kiln (1 site) Reused 3 times then disposed as hazardous waste (1 site) No data (1 site)	Partially or all recycled (4 sites)
Water-based	Sent to industrial laundry (5 sites)	Mixture incinerated (2 sites) Separated water and solids; incinerated solids (2 sites) Diluted mixture and discharged to POTW (1 site)	Partially or all recycled (5 sites)
UV-cured	Sent to industrial laundry (2 sites) No data (1 site)	Reused once before sending to cement kiln (1 site) On-site distillation; still bottoms disposed (1 site) No data (1 site)	Partially or all recycled (3 sites)

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